ESTIMATION OF EVOKED POTENTIALS USING HIGH ORDER STATISTICS-BASED ADAPTIVE FILTER

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Abstract-**This paper is to present a high order statistics-based adaptive interference cancel filter (AIC-HOS) to process evoked potential (EP). In conventional ensemble averaging method, experiments have to conduct repetitively to record the required data. In normalized LMS adaptive filter, inappropriate step size always causes deficiency. This AIC-HOS system has none of the above disadvantages. This system was experimented in somatosensory evoked potential corrupted with EEG. Gradient type algorithm is used in this AIC-HOS structure to regulate the SNR of EEG and EP. This method is also simulated with visual evoked potential and audio evoked potential. The results obtained are satisfactory and acceptable in clinical usage. The AIC-HOS is superior to normalized LMS using adaptive filter in that it converges easily. Moreover, it is not sensitive to selection of step size in stabilities in convergency.**

Keywords - **evoked potential, adaptive filter, high order statistics**

I. INTRODUCTION

Evoked potential is an important issue when any of the visual, audio, and somatosensory nerve is stimulated. This external stimulus will conduct through the nervous system and reaches the cortex. This will then evoked the brain cell reflective electrical activities.

The traditional method of processing evoked potential is averaging method. However, the result is highly sensitive to mild changes and the data collection experiment must be repeated several times in order to get a better recording result. Recording evoked potential is substantially improved through the use of adaptive filter [1][2]. This usual practice is to use normalized LMS in adaptive interference cancel filter. The most difficult problem is to obtain a good step size parameter. This is important for any slight changes in the step size parameter will jeopardize stability in convergency. Thus, AIC-HOS is suggested to solve this problem.

The fundamental structure of AIC-HOS [3] uses high order statistics as primary and reference inputs. Gradient type algorithm is used to obtain new values for the adaptive filter. It is used commonly to analyze and eliminate noise in wideband and narrowband. Moreover it is also used in the analysis of high order spectra, where power spectrum is its 2nd order spectrum. In poly-spectrum, gaussian signal components will be suppressed or eliminated, leaving non-gaussian components substantially visible. Moreover, its auto-correlation function will also suppress phase information. Thus, high order statistics [4] can be used to analyze or rebuild non-minimum phase signal. The AIC-HOS is not corrupted by uncorrelated white or colored gaussian noise source and is not so sensitive to step size changes. AIC-HOS is successfully used to compare normalized LMS (AIC-NLMS) in step size sensitivity and in different signal-noise-ratio (SNR) EEG signals.

II. METHODOLOGY

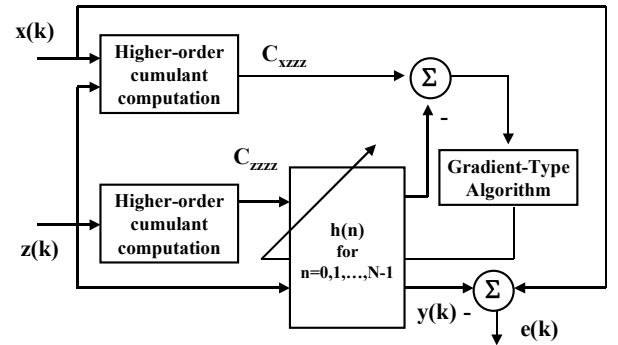The block diagram structure of AIC-HOS is shown in Fig.1.

Fig. 1. The block diagram structure of AIC-HOS

Let $x(k)$ and $z(k)$ denote primary input and reference input, satisfying

$$x(k) = s(k) + I(k) + n_p(k) \qquad (1)$$

$$z(k) = w(k) + n_r(k) \qquad (2)$$

where $s(k)$ denotes signal of interest, $I(k)$ is non-gaussian interference, and $w(k)$ is non-gaussian process signal.

$n_p(k)$ and $n_r(k)$ are mean measurement noise, stationary, zero-mean, white or colored gaussian process. Moreover, we assume that the relationship between the interference signal and the reference signal is a LTI transformation so that

$$I(k) = \sum_j g(j)w(k - j) \qquad (3)$$

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Abstract

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Let $y(k)$ be the adaptive filter output, satisfying

$$y(k) = \sum_{j=0}^{N-1} h(j)z(k-j) \qquad (4)$$

where N is the number of taps and vector $\mathbf{H_f} = \{h(n)\}$ for n= 0,1,…,N-1 is the adaptive filter coefficients.

To develop the AIC-HOS algorithm, we assume that there exists at least one order n (n>2) such that the nth order cumulants is not zero. Under this assumption, we find the fourth-order joint cumulants of primary input and reference input signal, $C_{xzzz}(m_1, m_2, m_3)$ and $C_{zzzz}(m_1, m_2, m_3)$. Using (4), the cumulant of adaptive filter output can be rewritten as

$$C_{yzzz}(m_1, m_2, m_3) = \sum_{j=0}^{N-1} h(j)C_{zzzz}(j+m_1, j+m_2, j+m_3) \quad (5)$$

Then the criterion of goodness is defined as the sum of the squared errors between two cumulants, thus

$$\xi_g = \sum_{m_1,m_2,m_3}[C_{xzzz}(m_1,m_2,m_3) - \sum_{j=0}^{N-1}h(j)C_{zzzz}(m_1,m_2,m_3)]^2 \quad (6)$$

We can rewrite (6) as matrix form

$$\xi = (\mathbf{C_{xzzz}} - \mathbf{C_{zzzz}H_f})^T(\mathbf{C_{xzzz}} - \mathbf{C_{zzzz}H_f}) \qquad (7)$$

The gradient of the criterion is given by

$$\nabla_f(k) = \frac{\partial \xi}{\partial \mathbf{H_f}(k)} = 2(\mathbf{C^T_{xzzz}} - \mathbf{C_{zzzz}H_f}(k) - \mathbf{C^T_{zzzz}C_{xzzz}}) \quad (8)$$

Then the weighted update equation is

$$\mathbf{H_f}(k+1) = \mathbf{H_f}(k) - \mu\nabla_f(k) \qquad (9)$$

where the range of step size is chosen as

$$0 < \mu < \frac{1}{trace(\mathbf{C^T_{zzzz}C_{zzzz}})} \qquad (10)$$

and $\mu(k) = \dfrac{\mu_f}{\alpha + trace(\mathbf{C^T_{zzzz}C_{zzzz}})}$ (11)

where α is the adaptive positive constant.

III. RESULTS

Data collected from somatosensory evoked potential used in this simulation. First, a set of 4000 data of SEP was processed using averaging method and was designated as the standard pattern. This was mixed with EEG signal to produce two sets of input data with SNR of –30 db and –5 db. These two sets are used to represent AEP and VEP respectively.

We compared the results obtained from using AIC-HOS and AIC-NLMS by changing the number of taps of the AR equations and the adaptive step size parameter. The mean square error (MSE) of these results are obtained after comparing them with the standard pattern. Table I is the MSE result for EEG signal with SNR equal –30 db. Table

II is the MSE result for –5 db. In these tables, N is the number of taps of AR equation, μ is the adaptive step size parameter.

TABLE I

THE MEAN SQUARE ERROR OF EP AFTER PROCESSING FOR –30 db

The taps of AR equation	Adaptive step size	Mean square error (MSE)	
		AIC-HOS	AIC-NLMS
N=8	μ=0.9	0.0755	0.0865
	μ=0.5	0.0527	0.0568
	μ=0.1	0.0253	0.0258
N=16	μ=0.9	0.0866	0.1344
	μ=0.5	0.0714	0.0824
	μ=0.1	0.0488	0.0260
N=24	μ=0.9	0.1480	0.1790
	μ=0.5	0.1055	0.1104
	μ=0.1	0.0335	0.0302

TABLE II

THE MEAN SQUARE ERROR OF EP AFTER PROCESSING FOR –5 db

The taps of AR equation	Adaptive step size	Mean square error (MSE)	
		AIC-HOS	AIC-NLMS
N=8	μ=0.9	0.0059	0.0134
	μ=0.5	0.0046	0.0097
	μ=0.1	0.0044	0.0043
N=16	μ=0.9	0.0107	0.0185
	μ=0.5	0.0089	0.0134
	μ=0.1	0.0050	0.0051
N=24	μ=0.9	0.0205	0.0219
	μ=0.5	0.0168	0.0157
	μ=0.1	0.0063	0.0058

Fig. 2. is the result of EP using different adaptive step size processed by AIC-HOS and AIC- NLMS with the taps of AR equation equal 16.
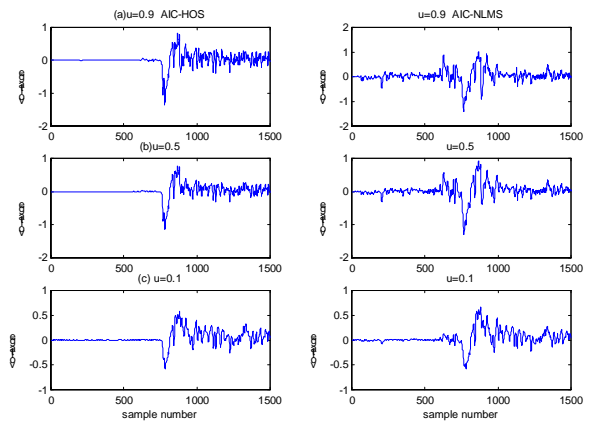

Fig. 2. The result of EP using different adaptive step size parameter processed by AIC-HOS and AIC- NLMS

The raw EP was then processed using AIC-HOS and AIC-NLMS to obtain their SNR. Maximum likelihood estimation was used to obtain SNR_{ML} [5] and correlation coefficient was applied to obtain SNR_r [6]. These results are shown in Table III for SNR_{ML}, Table IV for SNR_r.

TABLE III

THE SIGNAL NOISE RATIO (SNR_{ML}) OF EP AFTER PROCESSING

The SNR of input EEG	Adaptive step size	Signal-Noise-Ratio (SNR_{ML})	
		AIC-HOS	AIC-NLMS
-30 db	$\mu=0.9$	0.5895	0.1794
	$\mu=0.5$	0.9196	0.3468
	$\mu=0.1$	2.8165	1.8442
-5 db	$\mu=0.9$	75.8680	30.9434
	$\mu=0.5$	113.8590	50.8009
	$\mu=0.1$	326.1297	147.3680

TABLE IV

THE SIGNAL NOISE RATIO (SNR_r) OF EP AFTER PROCESSING

The SNR of input EEG	Adaptive step size	Signal-Noise-Ratio (SNR_r)	
		AIC-HOS	AIC-NLMS
-30 db	$\mu=0.9$	0.6495	0.1855
	$\mu=0.5$	1.0529	0.3654
	$\mu=0.1$	6.6500	2.6277
-5 db	$\mu=0.9$	96.5250	38.6388
	$\mu=0.5$	181.9523	73.2443
	$\mu=0.1$	577.0666	396.3891

IV. DISCUSSION

In Table I-II, the results significantly review that with the same number of taps of AR equation, AIC-HOS is more stable to AIC-NLMS when adaptive step size parameter changes. This is especially significant for taps equal 16. The convergence condition of AIC-NLMS is highly influenced by μ. However, for N equal 24, both methods are effected by μ. But for smaller μ, such as μ=0.1, AIC-NLMS has better results.

In Fig. 2., when N equal 16, with μ=0.9 or 0.5, the convergence property of HOS is much better than NLMS. When μ=0.1. EEG signal can be viewed as a changing narrowband noise. HOS is effective in suppressing wideband and narrowband interference. HOS out perform NLMS in this respect.

In Table III-IV, in EP application, the output from AIC-HOS has better SNR. But both methods, HOS or NLMS, are influenced by adaptive positive constant α and forgetting factor in cumulants.

V. CONCLUSION

Finally, from experiment and simulation, AIC-HOS has better attribute in converging and is not significantly affected by step size parameter. Thus, AIC-HOS is a good choice to be use in EP and other biomedical signal that need to eliminate wideband and narrowband interference.

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